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Evaluating Body Composition

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Introduction

In the study of food and how it plays its role in nourishing the body, many types of unsatisfactory nutritional states have been examined. The marked loss in body weight which results from simple deprivation of food, and the reason for it, have no doubt been recognized by man from time immemorial. Similarly, the association of obesity with the ingestion of large amounts of food must have been equally well appreciated. These two conditions are of course extreme or limiting examples of the relation of food to bodily condition which are obvious to the naked eye. Between these two extremes, on a scale so to speak, lie many conditions where this association is not so evident. These less obvious situations are far more numerous and likely to be seen in the population as a whole. Physicians, nutritionists, public health workers and others who may wish to express this relationship in some quantitative fashion find themselves dealing with a difficult problem, namely, how to express the individual's nutritional status with respect to leanness or fatness in reasonably accurate and quantitative terms.

The modern science of nutrition has demonstrated that specific disease can result from too prolonged subsistence on faulty diets. The deficiency diseases are examples of this. These disorders have been studied and much has been learned, not only about the pathological changes in one or more tissues which characterize them, but alterations in physiological functions and chemical composition of tissues and organs and various subtle changes in the intermediary metabolism of the body as a whole, which one may expect to occur in patients suffering from these diseases. Any truly comprehensive expression of the nutritional state in these individuals should of course take account of the knowledge available concerning all of these topics. We cannot hope, for some time at least, to be able to discover any expression that is truly comprehensive in this sense. Nevertheless, the value of having at hand any relatively simple formula dealing with at least the leaness or fatness problem seems obvious and requiring no extended argument.

Authors in this field have used different terms when discussing the association referred to above. *Nutritional status* seems to be appropriate and is preferred by many writers on the ground that what is being discussed is a particular state, in this case one related especially to nutrition, the extent to which that which nourishes the body, namely food, adequately performs this function.

Sinclair (1) prefers the term *nutriture* and distinguishes between nutrition as "a process or action" and nutriture as a "state or condition." Brozek (2) begins his paper entitled "Measuring Nutriture" with the following passage which

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summarizes very well the reasons why efforts directed toward discovery of quantitative expressions for measuring nutritional status can be worthwhile:

> "The evaluation of the morphological aspect of nutritional status (nutriture) is a practically important matter . . . Objective criteria for the assessment of nutriture are needed for the evaluation of the present status of different populations, for the demonstration of gains made by improved economic, agricultural and dietary practices, for judging nutritional deterioration in conditions of food emergency, and for the clinician's evaluation of nutriture of a given patient."

This passage was part of a paper read at a meeting of anthropologists to emphasize Brozek's view that these particular scientists have a contribution to make to what might be called *nutritional anthropometry*. It will be noticed in the Brozek passage just cited that *nutriture* appears to be used as synonomous with *nutritional status*. I prefer to use the latter term because it is less likely to be misinterpreted than a relatively new term such as *nutriture*, which has yet to gain wide acceptance. It probably does not make much difference what term is used provided an author offers some definition of it in his writing. The definition and discussion can indicate what the author intends his term to mean as well as what it should *not* be considered to mean. *Nutritional status* can cover a wide range of fairly specific conditions. Therefore, when it is used, I suggest that an appropriate qualification be indicated.

Possible Bases of Reference for Estimating Nutritional Status

The physicial measurements of the body — height, weight, circumference of the chest, et cetera—are the first parameters that come to mind in this connection. Of considerable interest in relation to our theme is measurement of the thickness of skin folds, because one of the important places where fat is stored is in the subcutaneous tissues. The usefulness of nutritional anthropometry here has already been mentioned.

There is considerable evidence that one or more of these physical measurements are to a considerable extent related to or dependent not merely upon nutritional status, but other factors such as genetic constitution and physical activity. It is a matter of common observation that many individuals and families seem to be lean or tall and spare in type, or else short and stocky with a tendency toward fatness. This certainly suggests the possibility of a characteristic type representing *genetic constitution*. The factor of *physical exercise* seems evident when one contemplates the athlete who can be either "hard and lean" (much muscle and little or no fat) or "overweight and flabby" depending upon how well he has "trained" for his races or other contests.

Data on *body composition* constitute an important approach to this problem. This information can be the result of actual analyses of corpses (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14), or it can be obtained indirectly by various techniques applied to the living individual. Illustrations of this appear later in this article. Theoretically, the amount of fat in the living body might also be estimated from

the amount of a nontoxic fat-soluble substance that is readily absorbed by the body fat. More correctly, this should be described as a partitioning of the substance between oil and water (the fat and nonfat tissues of the body). The gas cyclopropane has the qualities desired in such a test substance and has been used this way in the rat with considerable success (15). Another approach, somewhat similar in nature, has involved measurement of the amount of gaseous nitrogen eliminated by the organism under specific conditions such as are encountered, for example, in deep-sea diving where controlled decompression must be carried out after the dive (16, 17).

Still another approach involves the *measurement of body density or specific gravity* (12, 18, 19). This is based on the concept that there is what Behnke (18) calls the *lean body mass* (LBM) or what Keys and associates (19) prefer to designate the *fat-free body,* the composition and specific gravity of which are quite constant. In the thin individual this LBM may have little or no fat added to it. In other persons the varying amounts of fat added to it represent varying degrees of fatness. Since the specific gravity of body fat is much lower than that of the LBM, the specific gravity of the body as a whole should vary inversely with the degree of fatness, and of course directly with the degree of leanness.

With these several approaches available to us, it is obviously important that their relative values be determined if possible; that we learn to what extent the simpler ones that are more readily applied in the clinic and elsewhere give results agreeing with those yielded by the more complicated ones; and that the various limitations to them are properly elucidated and defined.

Body Build — Genetic Constitution

The earlier work in this field was done by physical anthropologists who developed the main anthropometric indexes by which they described body build. A sharp departure from the prevailing views came with the 1921 publication of Matiegka (20), also an anthropologist. He offered as a contribution to the testing of efficiency the idea that the mass of the skeleton, muscle and subcutaneous fat might be estimated by means of certain formulas. He called his methods "somatotechnic" in harmony with the term "psychotechnic" usually adopted for similar procedures in psychology. For example, he proposed the

$$M = k_3 \times r^2 \times L \qquad \text{or} \qquad M = k_4 \times c^2 \times L$$

formulas in which M signified muscle mass, k_3 and k_4 were "assumed to be coefficients (to be more accurately determined on corpses)" and "r and c, respectively, the average radius and the average circumference of the extremities without skin and without subcutaneous fat, and L, the stature." His method was tried out on twelve boys 16 to 17 years of age. He also applied his scheme to the data for three teachers of gymnastics. Of particular interest was his comparison of two women, one greatly emaciated, the other obese. In the former, the muscle mass and skin-and-fat were 151 and 33 per cents of the skeletal weights, respectively; in the obese woman the corresponding figures were 233 and 591 per cents.

Since 1921 workers in this field have accumulated much pertinent data and have looked for some common and more satisfactory basis of reference to use when making comparisons of this kind. Out of this work came the concept of using the *standard weight* of the individuals in question (what the weight should be for a given height, for example) as the proper basis to use.

Matiegka (20) used an x-ray technique for some of his work. A similar approach was used in 1936 by Rochlin (21) who used the term "roentgenoanthropology" in the Russian title of his paper. More recently this technique has been employed by Reynolds (22) studying growth in children and by others (23, 24) in pediatrics and related fields. However, too few anthropologists seem to find the study of the relation of anthropometry to body composition and, therefore, to nutritional status as interesting as "human biomechanics," "anthropometry of body's action" and the like. At the 1955 symposium on "dynamic anthropometry" held at the New York Academy of Sciences (25) only one of the sixteen papers presented there was in this field, namely, one by Brozek (26).

Because a tremendous volume of anthropological data has been collected representing all kinds of body measurements, attempts have been made to derive from them correlations between a relatively small number of them that might be used to describe an individual's physique. This has been called the method of factor analysis of body dimensions. As examples of work in this field one may cite the work of Cohen (27) who studied 50 male college students and dealt with 14 variables or separate measurements. A similar study was made on women by Rees (28). Hammond (29) applied "multiple general factor analysis to the delineation of physical types;" and study of his data led Thurstone (30) to the conclusion that four factors can be used to describe body types, namely, length of bone, horizontal size of the body trunk, size of the head, and a fourth factor involving primarily the size of the extremities and difficult to interpret.

Sheldon (31) developed a classification of people according to their body build, what he called their "somatype." According to this scheme there are three types, *endomorphs* (fat type), *ectomorphs* (thin type) and *mesomorphs* (a type in between these two extremes). To what extent these "types" can be considered as representing fairly fixed or "constitutional" characteristics, as Sheldon proposed, may be questioned, if for no other reason than the fact that the extreme types seem obviously to be related to nutritional status (thin type; fat type). Brozek and Keys (32) point out that even though "the somatotype ratings are markedly affected by changes in nutritional status and, in fact, may be considered as partial measures of nutriture," and this "may have eliminated the supposed virtue of the system as providing a permanent (constitutional) index, its possibilities as a measure of nutriture deserve to be critically examined."

Stuart and Sobel (24) noted a positive relationship between ratings for Sheldon's endomorphy and degree of fatness, but did not offer any quantitative data in support of this. Individuals classifiable as endomorphic in type tended to have a heavy *panniculus adiposus;* and ectomorphic persons tended to have a thin skin or a thin fold of subcutaneous tissues. This relationship was examined

quantitatively by Dupertuis and associates (33). They studied 81 healthy male individuals and recorded somatype ratings and body specific gravity. The subjects were selected to include representatives of the extremes of body build. Endomorphs, ("fat" subjects) also described as "round and soft," were found to have low values for body density in contrast to ectomorphs ("lean" subjects) who tended to have higher values. Brozek and Keys (32) made a similar study in a group of indivuals examined on two occasions. Their subjects were 31 young men, those who served in the study of starvation carried out at the University of Minnesota. These 31 men were examined first under control conditions and then after 24 weeks of starvation sufficient to result in a loss of one fourth of the original body weight and a marked loss of body fat. The coefficients of correlation between somatype rating and body density indicated a highly significant relationship, negative for endomorphy and positive for ectomorphy. The values were in essential agreement with the observations of Dupertuis and associates (33) except with respect to ratings for mesomorphy. Brozek and Keys (32) offered a table giving representative values of specific gravity and body fat content for various ratings of endomorphy and ectomorphy. These authors point out, however, that this approach to the question of body fat content, or expression of nutritional status "appears to be a devious and inefficient route, except under special conditions in which direct measurements on the living man were not or could not be made . . . It is the estimation of the absolute and relative amount of fat — which accounts for the largest part of the differences among adult individuals — of muscles, and of bones, which is the principal concern of nutritionally oriented anthropometry." If the critic still wishes to emphasize the role of genetic constitution in this situation, then I think his emphasis will have to be on the part played by genetic factors in determining rates of growth of various parts of the body (somagrowth), and enzyme systems involved in the handling of food and in intermediary metabolism (details of the functioning of the tissues resulting from the somagrowth). Genetic factors may be playing a role in the production of different body types, but not as great a role for every type as Sheldon (31) assumed. It could very well be that what is inherited is a set of mechanisms that makes it easier for the individual to respond in noticeable ways to the influence of food intake.

The 1921 paper by Matiegka (20) has already been discussed. His equations for accomplishing these objectives were based on stature and anthropometric characteristics of the extremities, and really involved measurements of skinfolds, circumferences and diameters of bones. The data from which the equations were derived were in part those found in the literature as well as others obtained from individuals actually measured by him. The equations failed, however, when applied to corpses. Since Matiegka's work in 1921 many related studies have been reported: *(a)* analyses of separate tissues as well as the entire body with respect to water, fat, minerals (and certain other substances in some instances); *(b)* measurement of the body's specific gravity; *(c)* the relation of body composition to specific gravity; *(d)* estimation of the fat content of the body from the

specific gravity; *(e)* the relation to specific gravity of the amount of body water and its distribution in the various compartments of the body; and *(f)* the relation of specific gravity values to those for the thickness of skinfolds.

Stuart, Hill and Shaw (23) and Reynolds (22) estimated the growth of bone, muscle and the overlying tissues by examination of roentgenograms of the leg. This represented an application of a technique first used by Nylin (34) who measured the thickness of the skin plus subcutaneous fat by means of the x-ray.

Rathbun and Pace (12) studied a group of 50 eviscerated guinea pigs and arrived at a formula relating the body's specific gravity to its fat content. Morales and associates (13) devised a theoretical basis for this approach and then devised a formula which they felt might reasonably be applied to man. In the study by Morales et al. (13) measurements were made of the mass and density of fat, bone, muscle, skin and nervous tissue. It was assumed *(a)* that the body may be treated as a five phase system; *(b)* that the fat component is the one subject to wide variation; *(c)* that the proportions of other components to some standard one, bone for example, are relatively constant; and *(d)* that the densities of skin and nervous tissue are approximately the same as for muscle. Equations were developed giving the amount of each tissue component as a fraction of the mass of bone. Using appropriate symbols for these several variables, equations were arrived at for expressing the total mass of the body as well as its average density. Study of these expressions indicated that the gross composition of the animal may be determined from a knowledge of *(a)* the body weight, *(b)* the body density, *(c)* the densities of fat, muscle and bone, and *(d)* the ratios of muscle, skin and nervous tissue to bone. With the help of a few simplifying assumptions, this theory was tested by a study of data derived from a group of guinea pigs. The fat content, determined by actual analysis, was plotted against specific gravity, which was also determined experimentally. The graph showed an inverse relationship to exist between fat content and specific gravity, and this was almost but not perfectly linear in character. By plotting on the same graph paper the data for muscle, skin, nervous tissue, viscera and bone, a chart was obtained from which it was possible to read off, for any given specific gravity of the entire body, the tissue fraction of that body mass represented by fat, muscle, skin, viscera, nervous tissue and bone. The validity of this theoretical approach having been demonstrated satisfactorily in the guinea pig, Morales et al. (13) felt justified in proposing an application of it to man. Their equations assume *(a)* that there is a lean body mass in the guinea pig and man which is of relatively uniform composition, and *(b)* fat is the only component exhibiting any appreciable relative variation. The following formula published by Rathbun and Pace (11) was the result of this work and has been widely used by many investigators:

$$\text{Per cent body fat} = 100\left\{\frac{5.548}{\text{Specific Gravity}} - 5.044\right\}$$

The lean body mass (LBM) would be equal to the measured body weight minus the fat content as

estimated by this formula. Zero fat content represents a body specific gravity value of 1.100 (LBM = 100%).

In much of the work of this sort there is the implicit assumption that when the body gains or loses fat, only fat is involved. Keys and Brozek (19) emphasize that this is not true "and any computation which ignores this fact is only an approximation at best." Against this criticism one might say that probably all estimates of body fat arrived at indirectly are only approximations. The real question is this: how good is the approximation? Quite apart from this rejoiner, the point made by Keys and Brozek has merit. Ljunggren (35) had made a special study of it and endeavored to describe in more concrete fashion the composition of obesity tissue. He concludes that the Keys-Brozek term "living obesity tissue" cannot be identical with the "excess fat" which Behnke has defined as the depot substance in the fat cells. Ljunggren therefore introduces "the concepts of non-obesity tissue and obesity tissue as substitutes for Behnke's concepts of lean body mass and excess fat" (p. 53).

The Rathbun-Pace formula and many others like it cannot of course be used unless one has a value for specific gravity. To determine this in any individual requires highly specialized apparatus and techniques and therefore the measurment is quite beyond the capabilities of most hospital clinics, physicians, nutritionists and others who may be interested in securing this information. Discovery of a relatively simple and reasonably accurate formula for calculating the body's specific gravity should therefore be of considerable practical use. Such a formula was reported recently (36). Before discussing it, however, some attention should be paid to another line of approach to an expression for estimating degree of fatness, the one based on consideration of body water, its distribution in the various compartments of the body, and the relation of this to body composition and specific gravity.

Estimation of Body Fat From Body Water Content

The concept of the lean body mass (LBM) has been described by Behnke (18) in these words: "The (upper) limiting value of the specific gravity for several different human populations is 1.100. One may tentatively suppose that this value represents the overall density of a lean body mass whose percentage composition is constant from individual to individual. This concept can be checked a posteriori . . . (Such results) support the concept that the mammalian body, in regard to such major components as water, protein, and minerals shows little variation throughout the whole period of adult life. The chief difference between man and lower mammals seems to be the higher mineral and somewhat lower protein content of man" (p. 1098). Additional support for this idea is afforded by studies on domestic animals (37, 38) showing that the fat-free body is of quite uniform composition. In view of this it should be theoretically possible to estimate the amount of body fat from the amount of body water as well as from the specific gravity. The preceding discussion of the work by Morales et al. (13) and Rathbun and Pace (12) supports the Behnke passage quoted

above. Studies of the relation of body fat to body water should be discussed briefly.

The basic technique for estimating body water content has been to inject a test solute, and then to measure the body's dilution and excretion of it. To be satisfactory for such use the test solute should have certain important properties which may be summarized briefly as follows: (a) it should dissolve readily in the body water and penetrate with that water rapidly throughout the tissues; (b) it should not be absorbed in or combined with or destroyed by other substances present in the body, or if it does it should prove possible to measure such action accurately and thus to predict the degree of variation from the ideal that is to be expected; (c) it should be eliminated from the body at a satisfactory measurable rate; (d) it should be easily and accurately measurable in the blood serum; and finally, of course, (e) it should be nontoxic in the amounts required for the test.

Numerous substances have been suggested for use as test solutes. Those that have gained thus far the most acceptance for estimating total body water are antipyrine, deuterium and the radioactive isotope of hydrogen (tritium). Urea has been both praised (39, 40, 41) and criticized (42, 43). From the work of San Pietro and Rittenberg (44) it appears that the water compartment measured by urea is somewhat smaller than that measured by deuterium. This is probably to be explained by the exchanges which this isotope of hydrogen makes with labile hydrogen in organic compounds in the body (45, 46). Hevesy and Jacobsen (47) estimated this labile hydrogen to be the equivalent of from 0.5 to 2.0 per cent of the body weight as water. In the tests made by Schloerb et al. (48) the heavy water 'space' was calculated to be greater than the total body water by about 1 per cent of the body weight.

As an example of how these techniques have been utilized in attempts to estimate body fat from body water, consider the plan proposed by McCance and Widdowson (39). It describes a "method for breaking down the body weights of living persons into terms of extracellular fluid, cell mass and fat, with some applications of it to physiology and medicine." These authors expressed the opinion that the measurement of specific gravity is not feasible; that the present techniques for measuring extracellular water are practical, and therefore a study of the relation of body water to fat content offers a worthwhile approach to the problem of estimating degree of fatness. Their paper reports such a study. Their method involves the following: *(a)* measurement of the *extracellular space* by the thiocyanate-injection technique; *(b)* correction for the *water in the red blood cells* by the Lavietes et al. (73) formula; *(c)* the assumption that the *blood volume* is 9% of the body weight for normal persons, and about 6 to 7% for the very obese; *(d)* the determination of *total body water* by the urea-injection technique; *(e)* calculation of the *weight of the cell mass* and of the *fat* in the body. The difference between total body water and volume of extracellular fluid is considered to be cell water. The cells are assumed to contain 67% water by weight. With respect to the minerals, the body of a normal person of average proportions was found to contain 6.2% of

his actual weight or 7.5% of the weight of the fat-free parts of the body (8). The fat is finally calculated as the body weight minus the weights of extracellular fluid, cell mass and minerals.

Using this technique, McCance and Widdowson (39) obtained data from seven normal and three obese men, five normal women and six obese women; in addition they studied the effects of undernutrition and rehabilitation in ten undernourished German war prisoners who had just returned from camps in Russia. With respect to this latter group, the body weights were quite normal for the heights after rehabilitation, but the breakdown of the body weights in accordance with the rationale of this method showed that the men were still abnormal in bodily constitution. A significant part of the weight that would ordinarily be interpreted as representing fat was found still to be water. Keys and Brozek (19) consider the McCance and Widdowson approach to be a perfectly reasonable one, but add that "for general application, including use with patients, the total body water estimation should be accompanied by an estimate of extracellular fluid, or possibly of body density, in order to avoid gross errors from differences in hydration." Insofar as this comment refers to extracellular water, it seems incorrect because the McCance-Widdowson method actually involves an estimation of this variable by the thiocyanate-injection technique. The comment about possible assistance in interpretation being rendered by an estimate of the specific gravity is really pertinent. As has already been pointed out, measurement of specific gravity is something beyond the capacity of most laboratories and clinics. It might be useful, however, to have a formula (36) for estimating this with reasonable accuracy from height and weight or any other data equally easy to obtain; how satisfactory its use could be would depend on how precise the estimates thus arrived at really were.

DaCosta and Clayton (49), in their study of dietary restriction and rehabilitation with 458 rats, measured the specific gravity of the eviscerated carcass by a water-displacement technique, and studied the interrelationships among the fat and water contents and the specific gravity of the total carcass. An *inverse* relationship was found between fat and water, and fat and specific gravity, and a *direct* relationship between water and specific gravity. They concluded, also, that "specific gravity is, therefore, as good an index of the water content of the whole animal as it is of the fat content." They made an observation that has some bearing on what McCance and Widdowson (39) noted at the end of the rehabilitation period for the German war prisoners who were studied. In the DaCosta-Clayton rats (49), early in the rehabilitation period the specific gravity did not correlate well with the body fat and water content as in more stabilized nutritional states, namely, after a long period of dietary restriction or after 70 to 95 days of dietary rehabilitation. Evidently the water and fat relationships change rapidly during early rehabilitation. These authors commented also, "in view of the significant correlations between specific gravity and a wide range of fat and water content, the relationships found by us for the normal animal may likewise hold for chronic pathological states" (p. 604). The inverse relationship between

fat and water supported the conclusions drawn by Haldi and Giddings (50) who noted an effect of diet on the water content of the skin of albino rats. The direct relationship between water content and specific gravity confirmed the findings of Messinger and Steele (51) and of Pace and associates (42). Messinger & Steele measured water content in 8 of their 9 individuals by the antipyrine-dilution technique; in the 9th individual it was measured by two methods, the dilution of deuterium as well as of antipyrine, with good agreement of the results. Pace et al. (42) used "radioactive H_2" for their determination of total body water.

Because diarrhea and dehydration phenomena are so important for the health of children, pediatricians have been greatly interested in such questions as, for example, the amount and distribution of water in the body of the growing child. Of the numerous papers in this field a few are worthy of comment here.

Robinow and Hamilton (52) measured the blood volume and extracellular fluid in groups of infants and young children. "It was found that the extracellular fluid volumes were very high for malnourished children and low for obese subjects. This was true even if the figures were calculated on the basis of body surface area; the same was found to be true in adults. The values increased with age when expressed on the basis of surface area, but decreased if on the basis of body weight."

Morse, Cassels and Schlutz (53) state that their work was done to supplement that of Robinow and Hamilton (52). Using the thiocyanate-injection method, the available fluid volumes were measured in 65 normal children ranging in age from 3 to 17 years. The interstitial fluid volume was calculated by subtracting the plasma volume and 70 per cent of the red cell volume from the available fluid volume. The paper presents numerous calculations and plots of the data. The available fluid volumes were found to be related to body weight by a linear equation, to stature by a semilogarithmic equation, and to surface area by an equation of the second degree. Equations of similar form were found to describe the relationship of the interstitial fluid volume to height, weight and surface area. Unlike the blood volume, the interstitial fluid volume was found not to vary with the state of nutrition of the child. The value of knowing, even if only approximately, the specific gravities of these children as a further aid in the interpretation of the data on water content seems evident. Fortunately, these authors give the heights and weights of each subject. Therefore, it will be possible to calculate for these children their respective specific gravities by a formula recently published (36). It will then be possible to study the relation of such values to those of other parameters.

In 1956 Friis-Hansen (54) published a valuable monograph entitled "Changes in Body Water Compartments During Growth." The interested student will find in it references to several pertinent books and other research publications. Friis-Hansen used the dilution of heavy water (deuterium) to measure total body water. The extracellular water was defined as the "thiosulfate volume of dilution." Intracellular water was obtained indirectly by subtracting the "thiosulfate volume" from the "deuterium oxide volume." Measurements were made in 93 infants and

children ranging from birth to 16 years of age. A total of 73 determinations of total body water and 51 measurements of extracellular water were made. Since heights and weights for each subject are given, it is possible to apply the new specific gravity formula (36) to these data. Such preliminary calculations as have already been made indicate the expected positive relationship between total body water and specific gravity. Further calculations will be necessary before one can say how good this suggested correlation really is.

Measurements of Skinfolds

One of the places fat is deposited in the body is in the subcutaneous tissues. Evidently, then, the thickness of a fold of the skin would be affected by the amount of fat present. It is known that some skin areas receive greater deposits of fat than others. By making numerous measurements on many persons it might be possible to show that the measurements of a certain area (or a group of areas) have a high correlation with the overall fat content of the body. If so, then a measurement (or set of measurements) of skinfold thickness will have been found that can assist in arriving at an estimation of the total amount of fat in the body. This subject has been reviewed in some detail elsewhere (55, 19) so only a few points will be mentioned here.

Several factors influence the results and, therefore, must be considered with care. There should be a *true* fold of the skin. In some areas it is difficult to meet this requirement. Obviously some areas are better than others with respect to this and are, therefore, better choices. The area of the skin under the plates of the calipers is a factor. This has been taken into account in the designing of instruments now manufactured for making such measurements. The pressure exerted by the calipers is a factor. Sandler (cited in 19) studied this point in some detail. For this reason the better instruments now manufactured are provided with a gauge so that the operator may select in advance and then really get the pressure desired for a given study. Other factors that suggest themselves and which have had some attention devoted to them are skin elasticity and skin turgor, particularly as affected by the individual's exposure to heat, and changes in body hydration, particularly as reflected in edema.

Newman (56), in his study of 10-day subsistance on so-called "survival rations" measured skinfolds on the abdomen, chest and arm. He checked the changes in body fat as reflected by the alterations in thickness of skinfolds by means of an equation derived by Brozek and Keys (57). Newman commented on the relatively simple technique that this involved and felt that the ease with which the data were collected made the method useful for studying larger groups where the determination of specific gravity directly is obviously impossible. A formula for estimating specific gravity from data on height and weight such as Cowgill (36) has developed could prove useful in situations like this.

The question of distribution of subcutaneous fat was studied by Edwards (58). His observations were made on from 130 to 150 individuals and covered 53 different sites. It might be supposed that by selecting a larger instead of fewer

number of sites, a better correlation of skinfold thickness with body fat content would be obtained, but this has not proven to be the case. Keys and Brozek (19) express the opinion that "one reaches rapidly a region of diminishing (or vanishing) returns in adding skinfolds beyond three or four well-selected and optimally weighted sites."

The choice of sites and their number must necessarily depend on the objective of the study. For nutritional surveys in relation to the leanness-fatness question, it is obviously advantageous to choose as few as possible and have them at places that are easily reached in both sexes. In the Brozek and Keys (57) study of students at the University of Minnesota and businessmen, 5 sites were chosen. In the Newman study mentioned above (56) only three sites were used, namely on the abdomen, the chest and the arm.

Estimation of Body Fat from Specific Gravity

The rationale of this approach has already been mentioned. In summary it is as follows: The *lean body mass* (LBM of Behnke and associates) or the *fat-free body* (Keys et al.) has a composition which is quite constant and a specific gravity value approximating 1.100. When this is "diluted" with fat which has a lower specific gravity (in the neighborhood of 0.92) the specific gravity of the body as a whole is correspondingly reduced. In the previous discussions attention was often paid to various studies in which data on body composition (water, minerals, fat particularly) were compared with those for specific gravity. From these investigations it is evident that knowledge of the specific gravity of living individuals can be useful in estimating the amount of fat in their bodies, and therefore their nutritional status with respect to leanness or fatness.

Until quite recently, actual measurement of the specific gravity of a living subject was not easily accomplished. To weigh an individual in air and then in water requires that a suitable tank be available. It is obvious that this kind of a measurement cannot be made on various types of patients in the hospital. When measuring the body's displacement in water an error is introduced by the dead space of the lungs and respiratory passages as well as by any gas that may be present in the alimentary tract. These sources of error must be studied, evaluated and in some manner allowed for when making the final calculation. Most, if not all, of the specific gravity data obtained experimentally on human subjects and reported in the literature have been obtained by this water-displacement technique (16, 17, 18, 59, 60). When such measurements have been made on experimental animals, guinea pigs and rats for example, another source of error has demanded attention, namely a correction for any air that may be entrapped by the hair when the body is immersed in water.

More recently a new technique has been devised which is not subject to at least some of these possible errors. Walser and Stein (61) described a method based on the principle of (a) placing the individual in a *chamber of accurately known volume;* (b) introducing a *known amount* of a chemically inert nontoxic gas like *helium;* (c) allowing for its proper *dilution* in the space of the chamber

not occupied by the individual; and then (d) carefully *analyzing* small samples of the respired air *for the gas after the dilution.* From the data thus obtained one can calculate the space in the chamber that is not occupied by the individual. Since the total volume of the chamber is known, the volume of the individual is easily calculated. In perfecting this method the chief obstacle that had to be overcome related to the problem of analyzing with sufficient accuracy the small quantities of the gas present. Walser and Stein (61) described a relatively simple application of this principle for use with small animals and reported data obtained with cats. Comparison of their method with the older water-displacement technique showed what was considered to be good agreement. The helium was determined in a Cambridge Analyzer which utilizes the thermal conductivity of mixtures of helium and dry air to give per cent helium concentration.

Siri (62) explored these ideas further and finally devised an apparatus large enough to take a human subject so as to make the method practical for hospital clinics and similar situations. This apparatus can also be used for measuring the basal metabolic rate, respiratory quotient and gas exchange in tissues. It can now be obtained commercially (63), but, as might be expected, is quite expensive. Specially trained technicians are needed to operate it properly.

A Formula for Estimating Specific Gravity of Men From Height and Weight Data

From the foregoing it seems evident that the development of any formula by which specific gravity might be estimated with reasonable precision from data easily obtained from any individual might very well prove to be of considerable practical significance. Obviously, proper use of any such expression requires that as much as possible be learned about its degree of precision and its limitations.

Thirty-one years ago Cowgill and Drabkin (64) published a formula for estimating the body surface area of the dog. This formula differed from others in the literature in that it contained an expression called the *nutritive correction factor.* In a footnote it was mentioned that human subjects differing widely in age show large differences in water content, and therefore "it is possible that similar differences in specific gravity exist. This might account for the failure of surface area formulae based on weight alone and found satisfactory for adult organisms to hold for very young individuals." At the time that footnote was written such data on specific gravity as were present in the literature seemed very crude and unsatisfactory, and therefore suitable exploration of this point could not be made. More recently Hardy and Drabkin (65) in their studies of the relation of body water to body size and fat content, reported that "an objective evaluation of overnutrition (excess fat) was derived from the nutritive index (Cowgill and Drabkin)." Hardy and Drabkin concluded that our old "nutritive index" serves really as an "excess fat index."

For various other reasons, which need not be gone into here (see 36), it was decided to test the possible relation of specific gravity values to various powers of height and weight. For this purpose Captain Behnke kindly furnished all of

his data pertaining to 176 men in the Navy. A formula was finally discovered (36). A simple and useful derivation from it is the following:

$$\text{Specific Gravity} = 0.8 \left\{ \frac{H_{cm}^{\,0.242}}{W_g^{\,0.1}} \right\} + 0.162$$

To test this expression it was applied to the data on height and weight for 23 individuals representing extremes of height or weight or both. Obviously the lowest possible value for the human body cannot be less than the specific gravity of human fat itself; this may be taken as about 0.92 (18, 19). The value yielded by the formula for perhaps "the most famous of fat men Daniel Lambert" who weighed 739 pounds (!!!) is 0.950.

When the formula was applied to the Benedict and associates' (67, 68) data for 51 newborn infants, the results indicated these infants to have an appreciable and theoretically unexpected amount of body fat, amounts averaging from 12 to 16 percent of the body weight. Later study of the literature revealed the pertinent papers by Widdowson (69) and McCance and Widdowson (70). These investigators reported analyses of newly born mammals from which it appears that, whereas the newborn of the rat, mouse, cat, rabbit and pig contain from 1.1 to 2.1 percent fat, that of the guinea pig contains about 10 percent, and the human newborn about 16 percent! The results of the calculation applied to the infants mentioned above are thus fully understandable and to be expected.

The formula was also applied to numerous data pertaining to well-fed American school children and "protein-deficient children" observed in Jamaica by Mackay et al. (71). On theoretical grounds, undernourished children would be expected to be thinner than children described as "well-fed," and therefore to have a higher specific gravity. This proved to be the case. Calculations based on data by de Bruin (72) pertaining to groups of boys with abnormal bodily dimensions likewise yielded results conforming to theory: Tall boys had an average value of 1.100 (range 1.112 to 1.088), and short boys an average of 1.082 (range 1.097 to 1.064); for the group of "abnormally thin" boys the average was 1.108 (range 1.120 to 1.095), and for the "fat boys" 1.066 (range 1.080 to 1.048). Values like these are what one would expect on theoretical grounds.

Some calculations were made using data by McCance and Widdowson (39) pertaining to German war prisoners returned from prison camps in Russia. These men were also studied with respect to the amount of body water and its distribution in the various "compartments" of the body. Observations were made at the time they arrived in Germany, and again after they had been rehabilitated by subsistence on a good diet. Rehabilitation was judged by the extent to which their body weights had returned to "normal" (average was 107 percent of the "standard weight"). The studies of body water showed that a considerable part of this "regained weight" was water and not fat as one might have supposed. This illustrates at least one shortcoming or limitation of the new formula. It is

likely to overestimate body fat content in individuals who present a history of prolonged undernourishment with considerable weight loss and then a period of rehabilitation on a good diet. It would be interesting to learn how long the period of rehabilitation must be in order to restore the individual not merely to his original weight but also to the body composition which that weight represented. This is but one of many studies that will obviously be needed in order to mark out more clearly the area of usefulness and limitations of the formula.

In this article an endeavor has been made to indicate the ideas that have been advanced and the various types of studies that have been carried out in an effort to measure "nutritional status" with particular reference to the question of the amount of fat in the body. It is quite evident that some promising advances have already been made but that much more work remains to be done on this interesting and important problem.

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